COST OF POWER IN JAPAN

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Cost of power in Japan
(10,000 K. W. steam, gas

COST OF POWER IN JAPAN

[100 00 K. W. Steam, Gas and Hydro-Electric Plants]

A THESIS

PRESENTED BY

TOMIGORO SASAKI

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APPROVED:

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Professor of Mechanical Engineering

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Dean of Engineering Studies

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PREFACE:

The author has made a study of this subject, both the theoretical and the practical sides, during the eight years he was with the Mechanical engineering Department of the Osaka Higher Technical College and his discussions are based upon the data the auther accumulated while in Japan.

Power plants in Japan have undergone marvelous developments within the last ten years. Yet these establishments have generally followed the technique of European and American plants in their preparation, modified, of course, by local condition. Naturally the principal machineries have to a large extent been imported from foreign countries. It is to be noted, however, that in recent years, prime-movers and generators have come to be turned out from domestic factories. But before the opening the present war, it was more economical to use the imported machineries.

The cost of establishing and operating power plants are always subject to local and labor conditions and their estimates vary more or less as compared with those of European or American plants.

In the following pages, the auther will endeavor to illuminate upon the subject, basing the figures upon what he has been able to investigate along these lines during the past few years while in Japan.

The author wishes to express his gratitude and indebtedness to Professor G.F.Gebhardt.

T. S.

COST OF POWER IN JAPAN

(10000 K.W. STEAM, GAS AND HYDROELECTRIC PLANTS)

INTRODUCTION.

There are three types of power plants for the production of electric current for the commercial purposes at this time, _Steam plants, Gas plants and Hydraulic plants.

In the last few years there has been tremendous progress and rapid improvement in steam turbines, internal combustion engines and hydraulic motors. Hence the selection of a power plant of any one of these types, for the production of electric current is a matter of great importance.

However, the essential problem is to provide a power plant at a minimum cost consistant with good and durable engineering work, together with subsequent minimum resultant working cost.

GENERAL DESIGN OF 10000 K.W. POWER PLANT.

The cost of a power plant depends upon its charactor and equipment and, to a very great extent, upon its capacity. Hence before making a comparison of the plants whether steam, gas or water, it is necessary to describe the general installation of the power plant to be designed.

General data :

Locatoin	Tokyo, Japan.
Charactor of load	Light and power.
Capacity of plant	10000 K. W.

THE SELECTION OF SITE.

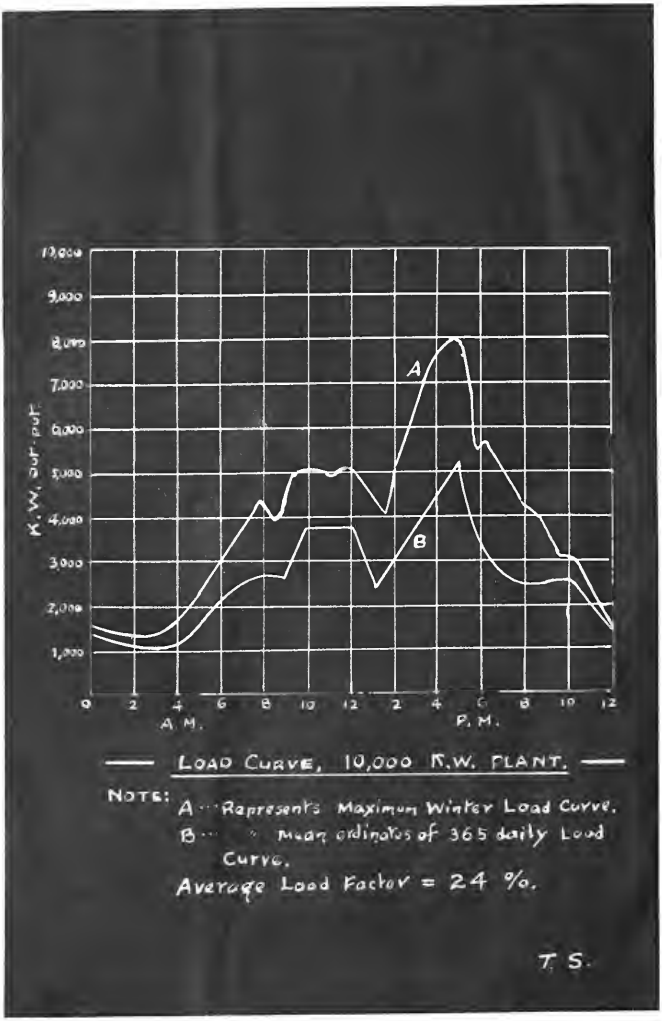
The important points which have to be considered in the cases of steam and gas plants are as follows:

1. A plantiful supply of water for cooling.
2. Transport of fuel.
3. Suitability of site relative to the position of center of distributing area, as affecting cost of feeders.
4. Liability of nuisance to adjoining properties.

5. Cheapness of land.
6. Cost of constructing foundation for plant, buildings and chimneys.

In the case of hydro-electric plant the location of main power station is situated a long distance from the city and the selection of it is decided by the water power to be used, but the points for consideration are :

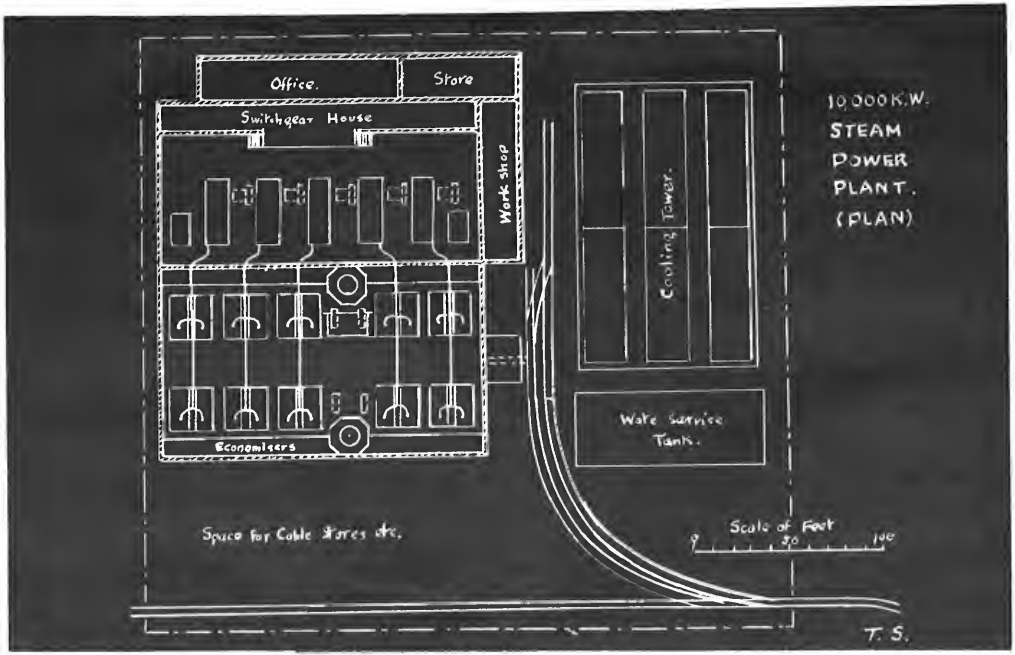
1. Suitability of site relative to position of center of distributing area, as affecting cost of feeder.
2. On the contrary to the above, remote from town, as affecting the danger tothe inhabtants.
3. Cheapness# of land.
4. Cost of constructing foundation for plant, and buildings.

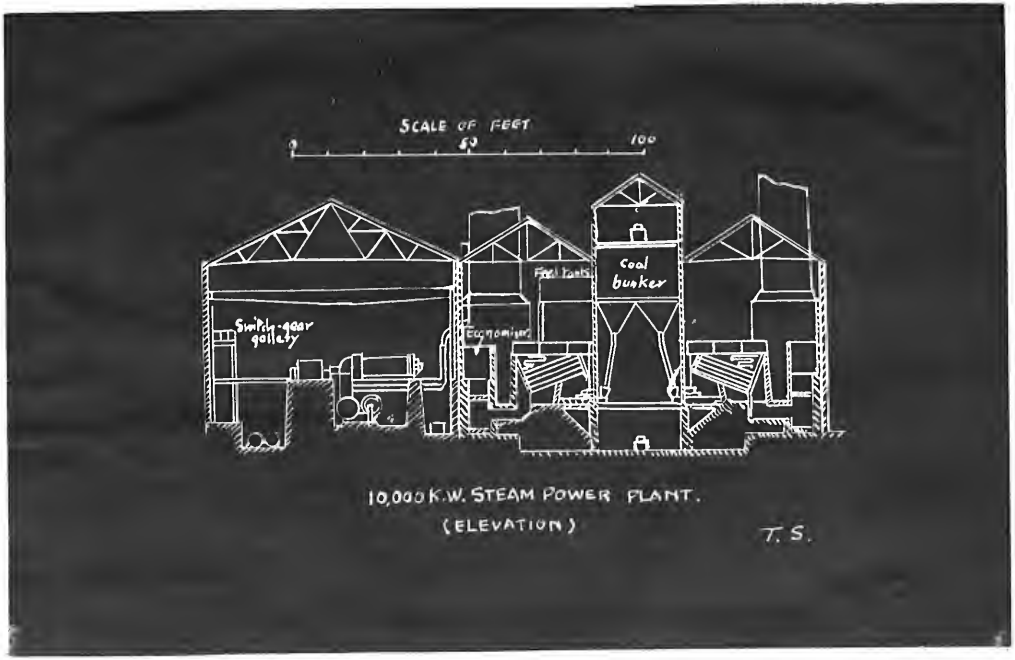


LOAD CURVE, 10,000 K.W. PLANT.

NOTE: A ··· Represents Maximum Winter Load Curve.
B ··· " Mean ordinates of 365 daily Load Curve.
Average Load Factor = 24 %.

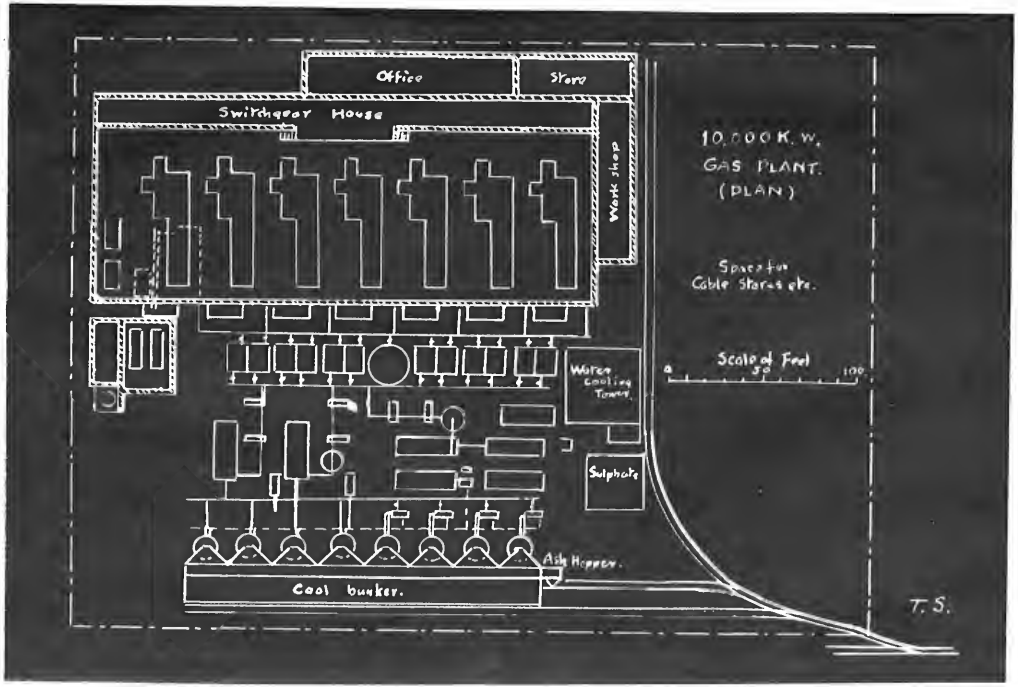
T. S.

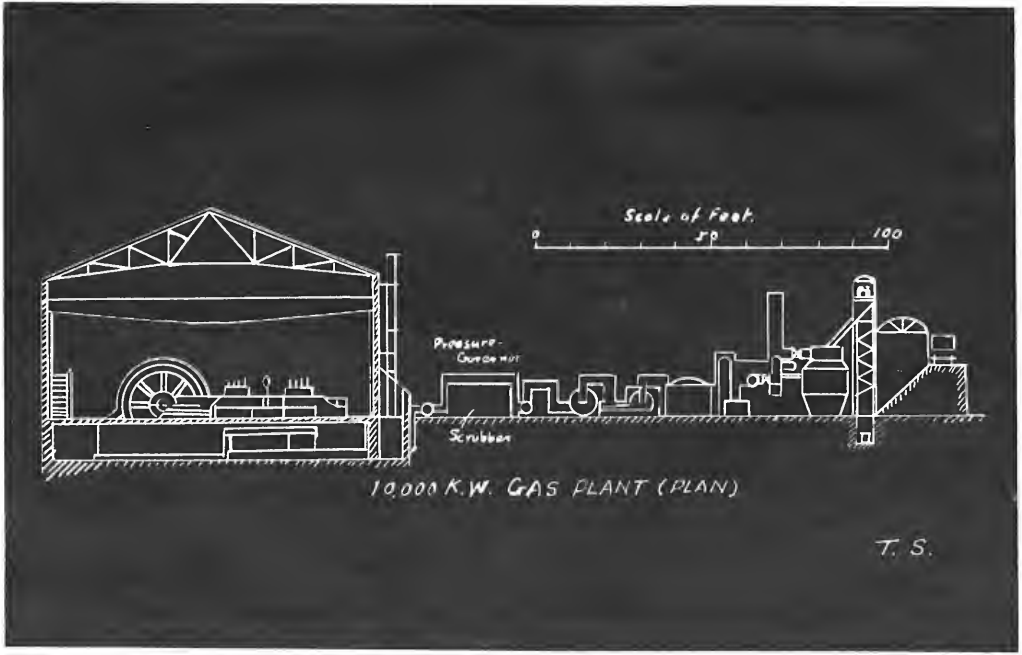

Office.
Store
Switchgear House
Work shop
Economisers
Space for Cable Stores etc.
Cooling Tower.
Water Service Tanks.
10,000 K.W. STEAM POWER PLANT. (PLAN)
Scale of Feet
0
50
100
T. S.



10,000 K.W. STEAM POWER PLANT.
(ELEVATION)

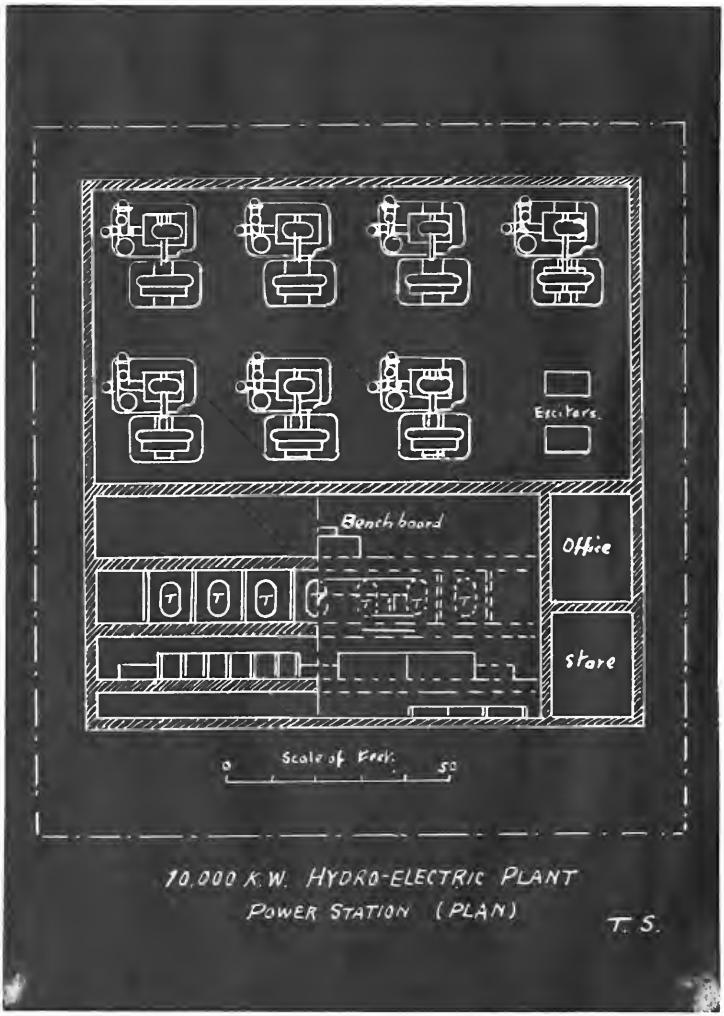
T. S.


Office
Store
Switchgear House
Work shop
10,000 K.W.
GAS PLANT.
(PLAN)
Space for
Cable Stores etc.
Scale of Feet
0
50
100
Water
Cooling
Towers
Sulphate
Ash Hopper.
Coal bunker.
T.S.



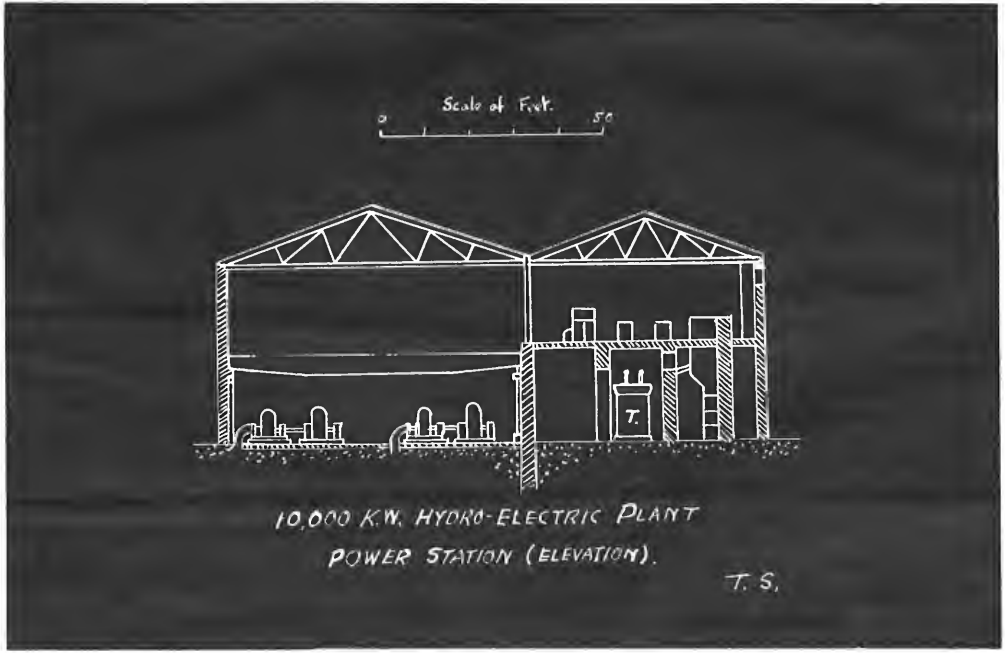
10,000 K.W. GAS PLANT (PLAN)

T. S.



10,000 K.W. HYDRO-ELECTRIC PLANT
POWER STATION (PLAN)

T. S.

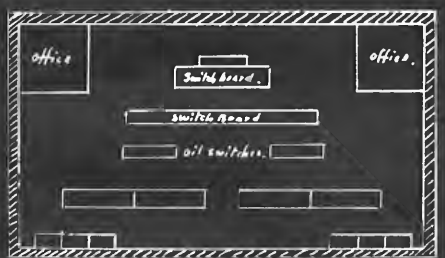


10,000 K.W. HYDRO-ELECTRIC PLANT
POWER STATION (ELEVATION).

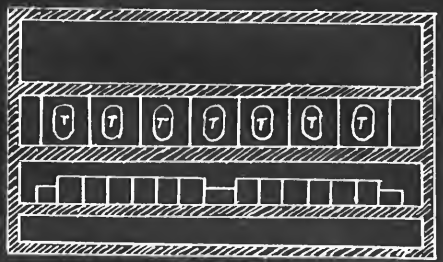
T. S.

10,000 K.W. HYDRO-ELEC. PLANT.
SUBSTATION.

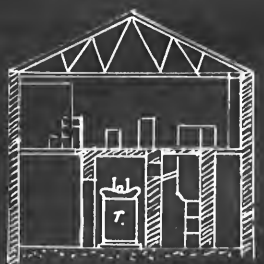
Scale of Feet. 50



(Upper Story)



(Ground Floor)



(ELEVATION) T. S.

POWER STATOIN EQUIPMENT.

(A) GENERATORS.

Steam plant.- There are 5 units of three phase, 2000 K.W. each rated out-put with over load capacity 33.5 per cent. The available K.W. demand is therefore, say 8000, allowing one unit in reserve.

Gas plant.- There are 7 units of three phase, 1450 K.W. normal, 1600 K.W. over load.

In the case of a gas plant it must be remembered that the engines are incapable of more than 12 to 15 per cent. overload.

The available K.W. demand is therefore, say 7500, allowable two units in reserve or one set in reserve and one under repair, asin resonable in a commercial gas power station.

Hydro-elecric plant.- There are 7 units of three phase, 1650 K.W. normal, 1980 K.W. overload.

Water turbines are about the same over load capacity to gas engines, and there are the transmission line loss of 10 per cent., and

the loss due to step up and step down transformers of 2 per cent., hence it has the same an amount of out-put on the switch board of the substation, as the other plants.

(B) PRIME MOVERS.

Steam plant.- 5-Parsons horizontal steam turbines to be directly coupled with generator.

Gas plant.- 7- Low speed horizontal double acting tandem gas engines to be directly coupled with generator.

Hydro-electric plant.- 7-Voith high head water turbines to be directly coupled with generator.

(C) STEAM BOILER.

Steam plant.- 20 - Water tube type 300 H.P. boilers taking the steam consumption of turbo-generator under working conditions,including the steam for auxiliaries, to be ammounted 20 pounds per K.W. generated, and five boilers consist a set of battery.

There are fitted with 4 Greens economizers.

(D) GAS PRODUCER.

Gas plant.- 4-Gas producers with recovery.

4-Gas producers without recovery.

Experience indicates that it is only worth while to recover sulphate of ammonia in plants having a larger demand than 3000 H.P., and then only on the higher load factors. Then an estimate may be made by the designer whether it will pay to introduce this more costly apparatus or not. There are the additional cost of sulpheric acid and bags to pack the sulphate of ammonia. Another points which ought to be considered is whether a compromise may not be economically affected by introducing so many recovery units to deal with the long hour running sets, and nonrecovery units for the peak sets.

(E) WATER WAY.

Hydro-electric plant.- The installation cost per K. W. varies greatly, depending on local conditions. It is usually considered that a cost of $66.50

per kilowatt represents the average of ordinary construction.

(F) SUBSTATION.

Hydro-electric plant.- There are 7 sets of 2000 K. W. step down transformers and the accessories.

(G) TRANSMISSION LINE.

Hydro-electric plant.- This is depending upon the distance from the power station to the substation and in the case assume that a cost of $35.0 per kilowatt represents the average of ordinary construction.

(H) FOUNDATION, SETTING AND ERECTING EXPENCES.

These expences are depending upon the charactor, and sizs of machines to be settled, and the averaged values are as follows.-

Steam plant.-

7 to 8 per cent. of the cost of generating room machinaries.

3to 4 per cent. of the cost of steam boilers and accessories.

Gas plant.-

8 to 10 per cent. of the cost of generating room machinaries.

1 to 1.5 per cent. of the cost of gas producers.

Hydro-electric plant.-

10 to 12 per cent. of the cost of power station machineries, including the expence of exhaust water way.

Setting and Erecting Expences.

Steam plant.-

2 per cent of the cost all machineries.

Gas plant.-

2 per cent. of the cost of generating room machineries.

3 per cent. of the cost of producers.

Hydro-electric plant.-

2 per cent. of the cost of power station machineries.

1.5 per cent. of the cost of substation machineries.

LAND AND BUILDING.

The estimated costs of land and building are determind on the basis of cost per 6 feet square of the space in Japan (colled"One Tsubo").

Steam plant.-			
			$
Land	108414	sq.ft.	18,069.00
Building	38700	"	96,750.00
		Total	114,819.00
Gas plant.-			
			$
Land	133668	sq.ft.	22,278.00
Building	37800	"	94,500.00
		Total	116,778.00
Hydro-electric plant.-			
Power Station:			
			$
Land	22766	sq.ft.	3,162.00
Building	15192	"	42,200.00
Substation:			
Land	16592	"	2,832.00
Building	5070	"	12,690.00
		Total	60,884.00

CAPITAL COST.

Steam Plant.-

	$
5 -2000 K.W. Parsons turbogenerators with switchboards and accessories.	201,735.00
5 -Surface condensers with pumps.	71,635.00
Cooling tower plant.	37,500.00
20 -Water tube boilers with mechanical stokers, economizers, superheaters, feed pumps, tanks and all pipe work.	198,630.00
Chimneys and flues.	31,000.00
Exciters.	8,330.00
Overhead travelling crane.	4,465.00
Land and building	114,819.00
Steel structual work, coal bunkers, coal and ash handling apparatus.	45,000.00
Water well and pumps.	6,265.00
Foundation and setting etc.	41,200.00
Total	760,579.00

$76.1 per K.W. generated.

Gas Plant.-

		$
7	Gas engines of 8 cylinder 2 tandem, with complete accessories.	576,000.00
7	Parsons Peebles 3 phase alternators, 3450 volts, 50 cycles.	124,950.00
4	Mond gas producers and accessories with ammonia recovery plant.	172,000.00
4	Mond gas producers and accessories without recovery plant.	81,500.00
	Steam raising plant.	15,250.00
	Water cooling towers.	4,500.00
	Compressed air plant.	3,800.00
	Steam boilers with fittings.	67,000.00
	Exciters with steam engine.	12,500.00
	Overhead travelling crane.	11,400.00
	Ferranti switchboard.	11,350.00
	Land and building.	116,778.00
	Foundation and setting etc.	105,000.00
	Total	1293,028.00

$129.4 per K.W. of station capacity.

Hydro-electric Plant.-

(1) Power station.

Water ways and pipes.	798,000.00
7 Westinghouse 1650 K.W. 3 phase, 50 cycle 3300 volts, generators with switchboards etc., and 2 of 150 K.W. exciters.	77,190.00
7 2500 H.P. Voith water turbines with governors and 2-250 H.P. turbines for exciters.	42,850.00
7 2000 K.W. Transformers.	29,850.00
2 Route transmission line 50 miles.	350,000.00
Overhead travelling crane.	4,465.00
Transporting expence.	16,350.00
Land and building.	45,362.00
Foundation and setting etc.	39,700.00

(2) Substation.

7 Transformers and switchboards etc.	38,795.00
Land and building.	15,522.00
Foundation and setting etc.	1,250.00
Total ~~all~~ over	1453,334.00

$145.4 per K.W. of distributing switchboard at substation.

OPERATING COST.

(A) FUEL.

The points which have to be considered in the fuel of steam and gas power plants are as follows:

1. The actual output, which in an electric generating plant will be expressed in K.W. generated.
2. The no load losses, which include windage, and electrical losses incured inrunning the generator on open circuit, together with all power required, for exciters, pumps andother auxiliaries.
3. Stand by losses of banking boilers or producers.
4. The ratio of the actual ascertained fuel consumption under day by day working conditions to the theretical consumption base upon test results applied to them 1,2 and 3 which is called discrepancy factors.

Steam plant._

Total coal consumption = 31,968 tons per year.

i. e. 3.48 pounds per K.W. hr.

Cost of coal per ton	$ 3.50
B.t.u. per pound	13,000

Then the total cost of coal per annum =$111,888.00

Gas plant.-

Total coal consumptoin = 19,646.4 tons per year.

i.e. 2.09 pounds per K.W. hr.

And the coal is same as in above case, then the total cost of coal per annum is $ 68,762.50.

Sulphate of Ammonia:

In this gas plant will produce about 561 tons of sulphate of ammonia in the recovery apparatus. Assuming the market price of the sulphate of ammonia is $ 55 per ton, then the amount of this byproduct is $ 30,855.00 per year.

(B) OIL.

The cost of lubrcating oil is $ 0.475 per gallon.

Steam plant.$

$ 0.00007915 per K.W. hr. generated

i.e. Cost of oil per year = $ 1,662.15

Gas plant.-

0.37 gallon per 1000 M.P. hr. of the gas engines

i.e, 12,932 gallons per year, and its cost is

$ 6,142.70

Hydro-electric plant.-

The average oil consumption is $ 0.0000189 per K.W. hr. Hence total cost of oil per year is $ 398.00.

(C) WASTE.

Steam and Gas plants.-

The average amount is $ 0.00004 per K.W. hr, generated, i.e. $ 840.00 per year.

Hydro-electric plant.-

The average amount is $0.00000384 per K.W. hr. generated, i.e. $ 83.41 per year.

(D) SULPHURIC ACID.

Sulphuric acid has to be added, ~~to~~ 1 ton of sulphuric being required for each ton of sulphate of ammonia obtained. Hence the total amount of sulphuric acid required is 561 tons per year, and it should cost $ 9.00 a ton; i. e. the total cost of sulphuric acid is $ 5,274.00 per year.

(E) LABOUR CHARGE.

Steam Plant:

1	Charge engineer		$ 1,000 per year
2	Assistant "	($25 @ month)	600 " "
3	Switchboard attendants	($12.5 ")	450 " "
3	Drivers	($.50 @ day)	540 " "
2	Assistant drivers	($.20 @ day)	144 " "
3	Fire men	($.30 ")	324 " "
9	Boiler house hand	($.20 ")	486 " "
3	Men for coal&ash handling	($.20 ")	162 " "

Total labour charge per year $ 3,706.00

Gas Plant:

1	Charge engineer		$ 1,000 per year
1	Chemist		600 " "
2	Assist. engineers	($25 @ month)	600 " "
3	Switchboard attendants	($12.5 ")	450 " "
10	Drivers	($.50 @ day)	1,800 " "
2	Cleaners	($.20 ")	144 " "
3	Producer hand	($.50 ")	540 " "
6	Assistant "	($.30 ")	648 " "
7	Ammonia recovery hand	($.20 ")	504 " "

2	Men for coal & ash handling ($.20 @ day)	$ 144 per year
	Total labour charge per year	$ 6,430.00

Hydro-electric Plant:

(1) Power station.-

1	Charge engineer	$ 1,000 per year
1	Civil engineer	600 " "
2	Assistant engineers ($25 @ month)	600 " "
1	Assistant civil " (" ")	300 " "
3	Switchboard attendants ($12.5 ")	450 " "
3	Drivers ($.50 @ day)	540 " "
2	Assistant drivers ($.20 ")	144 " "
3	Men for watching water way (")	162 " "

(2) Substation.-

1	Charge engineer	450 per year
1	Assistant "	300 " "
1	" " charging transmission line	300 " "
3	Switchboard attendants ($12.5 @ M.)	450 " "
1	Cleaner ($.20 @ day)	72 " "
6	Men for watching transmission line ($.30 @ day)	648 " "
	Total labour charge per year	$ 6,016.00

(F) MAINTENANCE.

The total expences of repairs and maintenance to the entire plants in steam and gas are 0.9 to 1 cet. per unit generated, and for the hydro-electric plant 2 per cent. of the fixed charge.

Steam and Gas plants.-

$ 20,000.00 per year.

Hydro-electric plant.-

$ 27,960.00 per year.

(G) DEPRECIATION.

This depend on how the plants are worked and maintained, and upon the load factor of the plnat. It may generally be taken at 5 per cent. over the whole plant.

Steam plant:-

$ 38,039.00

Gas plant.-

$ 64,653.90

Hydro-electric plant.-

$ 72,666.70

(E) INTEREST.

This depends ,of course, upon conditions: e.g. whether municipal or private, and also upon the standing of the company. Interest usually calculated at 5 per cent.

Steam plant.-

$ 38,029.00

Gas plant.-

$ 64,653.90

Hydro-electric plant.-

$ 72,666.70

(I) TAXES AND INSURANCE.

These depend upon the location of the plant, but an average charge for this item is 1.5 per cent.of the fixed charge of theplnat.

Steam plant.-

$ 11,300.00

Gas plant.-

$ 19,337.00

Hydro-electric plant.-

$ 21,750.00

Cost of Power (10,000 K.W. Steam Plant)

Load factor per cent.	24	30	35	40	45	50	55
Total K.W. hr. generated.	21,000,000	26,250,000	30,625,000	35,000,000	39,475,000	43,750,000	48,125,000
Total coal in tons.	31,822	36,591	40,726	44,883	49,042	53,429	57,912
Cost of coal at $3.50 ton.	111,377	128,069	142,541	157,093	171,649	187,003	202,692
Oil and waste in $.	2,502	3,128	3,649	4,170	4,692	5,212	5,734
Labour in dollars.	3,706	3,706	3,706	3,706	3,706	3,706	3,706
Maintenance	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Depreciation and interest 10 per cent. of capital.	76,058	76,058	76,058	76,058	76,058	76,058	76,058
Taxes and insurance.	11,300	11,300	11,300	11,300	11,300	11,300	11,300
Total cost.	225,454	242,260	257,254	272,327	287,405	303,279	319,490
Cost per K.W. hr. (cents)	1·0726	·923	·840	·778	·728	·693	·665

T. S.

COST OF POWER (10,000 K.W. GAS PLANT)

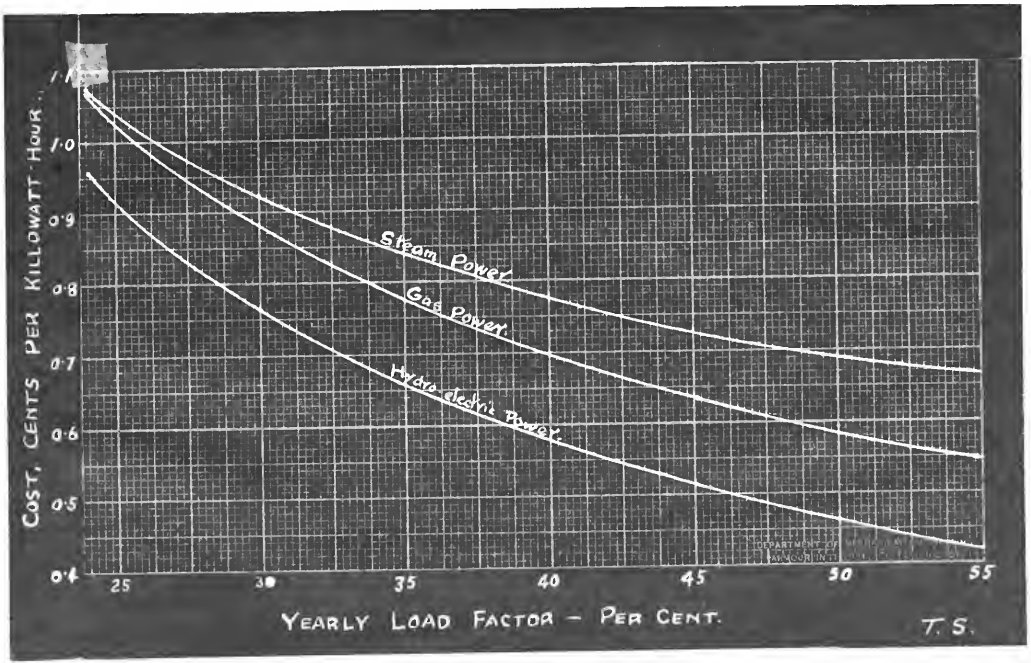
Load factor per cent.	24	30	35	40	45	50	55
Total K.W.hr. generated	21,000,000	26,250,000	30625,000	35,000,000	39,475,000	43,750,000	48,125,000
Total coal consumption, Tons.	19,646	22,270	24,500	26,759	29,037	31,326	33,626
Cost of coal ($ 3·50 per ton)	68,763	77,944	85,750	93,657	101,628	109,642	117,690
Sulphate of ammonia, saled.	-30,855	-34,964	-38,514	-42,012	-45,587	-49,182	-52,784
Sulphoric acid	5,049	5,720	6,301	6,873	7,458	8,046	8,635
Oil and waste	6,983	8,728	10,183	11,638	13,126	14,547	16,002
Labour	6,430	6,430	6,430	6,430	6,430	6,430	6,430
Maintenance	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Depreciation and interest.	129,308	129,308	129,308	129,308	129,308	129,308	129,308
Taxes and insurance	19,337	19,337	19,337	19,337	19,337	19,337	19,337
Total cost	225,204	232,463	238,758	245,195	251,664	258,093	264,582
Cost per K.W.hr. (cents)	1·0707	·884	·777	·699	·637	·590	·549

T. S.

COST OF POWER (10.000 K.W. HYDRO-ELECTRIC PLANT)

Load factor per cent.	24	30	35	40	45	50	50
Total K.W. hr. generated.	21,000,000	26,250,000	30,625,000	35,000,000	39,375,000	43,750,000	48,125,000
Oil and waste	479	598	698	798	896	1,000	1,097
Labour	6,016	6,016	6,016	6,016	6,016	6,016	6,016
Maintenance	27,960	27,960	27,960	27,960	27,960	27,960	27,960
Depreciation and interest	145,333	145,333	145,333	145,333	145,333	145,333	145,333
Taxes and insurance	21,750	21,750	21,750	21,750	21,750	21,750	21,750
Total cost	201,538	201,658	201,758	201,857	201,955	202,059	202,157
Cost per K.W. hr. (cents)	.960	.768	.659	.577	.512	.462	.420

T. S.


COST, CENTS PER KILOWATT HOUR.
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
25
30
35
40
45
50
55
YEARLY LOAD FACTOR – PER CENT.
Steam Power.
Gas Power.
Hydro-electric Power.
T. S.